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厦门大学

硕士学位论文

九龙江口秋茄红树林土壤–大气温室气体通量随植被恢复变化的研究

Studies on Changes in Atmospheric Greenhouse Gas Fluxes from Soils of *Kandelia obovata* Mangrove Forests with the Development of Restored Vegetation in Jiulong River Estuary

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摘 要

选取福建九龙江口南岸浮宫镇霞郭村秋茄红树林研究断面，研究夏季白天的一个潮汐周期内未被潮水浸没时红树林土壤 3 种温室气体（N_2O、CH_4 和 CO_2）通量变化情况，探究滩位和潮汐日变化对该地区红树林土壤大气界面温室气体通量的影响。在此基础上，以光滩为对照和恢复的起点，再选取 26 年生和 50 年生的人工秋茄红树林以及天然成熟林代表不同恢复阶段，探讨不同植被恢复阶段红树林土壤-大气界面这 3 种温室气体通量随植被恢复时间的关系，并分析植被恢复导致的土壤环境变化对温室气体通量的影响，为人工红树林的功能恢复提供参考依据。

夏季大潮日和小潮日白天的潮汐周期内 3 种温室气体通量的滩位变化研究结果显示，大潮日红树林土壤这 3 种温室气体通量均没有显著的滩位差异，小潮日 N_2O、CH_4 通量也没有显著的滩位差异，但 CO_2 通量却表现出从陆向海降低的趋势。3 种温室气体通量在小潮日的潮汐周期内日变化特征不显著，且 N_2O 和 CH_4 通量在大潮日和小潮日没有显著差异。土壤温度是影响红树林土壤温室气体通量日变化的重要因素。

不同恢复阶段红树林 3 种温室气体通量研究显示，N_2O 年均通量范围为 0.17~0.76 μmol m^{-2} h^{-1}，CH_4 年均通量范围为 4.52~73.27 μmol m^{-2} h^{-1}，CO_2 年均通量范围为-0.22~4.35 mmol m^{-2} h^{-1}，N_2O、CH_4 和 CO_2 通量均表现出显著的季节差异，总体上为夏季高、冬季低。3 种温室气体通量均表现出随植被恢复的差异，CO_2 和 CH_4 通量表现出随植被恢复时间的延长而增加的趋势，而 N_2O 通量则表现出植被恢复的初期较低，随着植被恢复时间的延长而增加的趋势。根据不同温室气体的增温潜势，将九龙江口红树林湿地土壤 3 种温室气体通量换算得到总的 CO_2 当量，其年均通量为 124.32 mg CO_2 m^{-2} h^{-1}，其中 CO_2 是最主要的贡献气体，且总 CO_2 当量通量也表现出随着植被恢复时间的延长而增加的趋势。

不同恢复阶段红树林土壤理化性质研究结果表明，土壤 Eh、含水率、pH、氨态氮、硝态氮、有机碳、总氮、总磷和碳氮比等指标中，除总氮含量外均表现出显著的季节变化动态。红树林植被恢复对土壤各理化指标有显著的影响，其中氨态氮表现为在植被恢复后含量下降，而随着植被恢复时间的延长，氨态氮含量

增加， pH 表现为随植被恢复时间的延长而下降，有机碳和总氮含量以及碳氮比表现出随着植被恢复时间的延长而增加。通过对土壤理化性质与 3 种温室气体通量的相关性分析，发现红树林植被恢复进程对土壤 N_2O 通量的影响是由于土壤氨态氮含量的变化而造成的，而对 CH_4 和 CO_2 通量的影响则主要由于土壤有机碳和总氮含量的变化而造成的。

总之，随着秋茄植被的恢复，土壤理化性质发生变化，从而导致红树林土壤-大气界面温室气体通量的变化。

关键词：河口；红树林；温室气体通量；植被发育

Abstract

In order to understand the spatial and diurnal variations of greenhouse gas fluxes from mangrove soils, the fluxes of N_2O, CH_4 and CO_2 were measured in one *Kandelia obovata* mangrove forest in Jiulong River estuary, China, when mangrove soils were exposed to air during one tidal cycle on spring or neap day in summer. Based on that study, effect of age of restored mangrove forests on the atmospheric greenhouse gas fluxes from soils were investigated, choosing one bare flat (K0), one 26-year old restored forest (K26) and one 50-year old restored mangrove forest (K50) as well as one natural mature forest (MF) as representative forests. Seasonal variations of greenhouse gas fluxes and soil parameters from all these mangrove forests with different ages were measured. The correlation relationships between greenhouse gas fluxes and soil parameters were tested in order to understand the variation of greenhouse gas fluxes with the development of restored mangrove forests.

There were no significant differences in the fluxes of N_2O, CH_4 and CO_2 from different study sites (inner site and outer site) in the present mangrove forest during the spring day of summer. It was the same for the fluxes of N_2O and CH_4 during the neap day, while CO_2 showed significantly higher fluxes at the inner site than the outer site. Significantly diurnal variations of fluxes of the three greenhouse gases in one tidal cycle were not found during the neap day. Moreover, the average fluxes of N_2O and CH_4 were similar between spring and neap days, while fluxes of CO_2 were a little higher on neap day than on spring day. The soil temperature and inorganic nitrogen contents were important factors that affect the diurnal variations of the greenhouse gas fluxes.

As for the effect of age of restored mangrove forests on the fluxes of atmospheric greenhouse gases from soils, annual fluxes of N_2O, CH_4 and CO_2 ranged from 0.17 to 0.76 μmol m^{-2} h^{-1}, 4.52 to 73.27 μmol m^{-2} h^{-1} and -0.22 to 4.35 mmol m^{-2} h^{-1}, respectively. Fluxes of the three greenhouse gases differed significantly among sampling seasons, as well as among restored forests with different ages. In general,

fluxes of the three greenhouse gases were highest in summer and lowest in winter. Meanwhile, fluxes of CH_4 and CO_2 increased with the development of restored forests, but fluxes of N_2O from soils firstly decreased after the replanting of vegetation and then increased with the later development of vegetation. Total CO_2-equivalent fluxes of the three gases from soils of restored forests with different ages，indicating their global warming potential, ranged from 82.33 to 674.92 mg CO_2 m^{-2} h^{-1}, and CO_2 was the most dominant in the total flux in all mangrove forests. Therefore, total CO_2-equivalent fluxes also increased with the development of restored forests.

Soils were also sampled after the sampling of greenhouse gases. Soil parameters of Eh, water content, pH, ammonia nitrogen, nitrate nitrogen, organic carbon, total nitrogen, total phosphorus and ratio of carbon and nitrogen were analyzed. All soil parameters showed significant differences among sampling seasons, while soil total nitrogen was an exception. Significant variations of soil parameters among restored forests with different ages were found though different soil parameters showed different variation patterns. Soil ammonia nitrogen contents firstly decreased after the replanting of vegetation and then increased with the later development of vegetation, like the variation of N_2O fluxes. The value of soil pH decreased with the development of vegetation, while soil organic carbon content, total nitrogen content and ratio of carbon and nitrogen increased with the development of vegetation. Furthermore, fluxes of N_2O among restored forests with different ages were significantly correlated with the contents of soil ammonia nitrogen, while fluxes of CH_4 and CO_2 were significantly correlated with the contents of soil organic carbon and total nitrogen.

As a summary, with the development of restored mangrove forests, soil parameters varied and those soil parameters were vital factors that caused the variations of greenhouse gas fluxes from mangrove soils.

Key Words: Estuary; Mangrove forests; Greenhouse gas fluxes; Restoration

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